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RESEARCH MEMORANDUM

ESTIMATION OF NEUTRON ENERGY FOR FIRST
RESONANCE FROM ABSORPTION CROSS
SECTION FOR THERMAL NEUTRONS

By Donald Bogart

Lewis Flight Propulsion Laboratory
Cleveland, Ohio

FOR REFERENCE

NOT TO BE TAKEN FROM THIS ROOM

NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS

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SUMMARY

Examination of published data for some 52 isotopes indicates that the neutron energy for which the first resonance occurs is related to the magnitude of the thermal absorption cross section. The empirical relation obtained is in qualitative agreement with the results of a simplified version of the resonance theory of the nucleus of Breit-Wigner.

INTRODUCTION

The sparsity of information concerning neutron cross section for stable isotopes in the rather wide neutron energy range occurring in nuclear reactors makes evaluation of the influence of materials to be used in reactors quite difficult. In particular, neutron absorption data are in many cases almost completely lacking; for most isotopes, only the thermal values and a few isolated higher energy values are known. For many nuclei, neutron resonances occur at particular neutron energies in the neighborhood of which very large cross sections are observed. As indicated in reference 1, appreciable portions of these resonances may be absorptive.

The theory of neutron capture would provide a means for computing cross sections if it were possible to carry out the necessary calculations with respect to the nuclear energy levels of the compound nucleus. Such calculations have proved, for the most part, to be impossible. The theory, however, does indicate the absorption cross section below the first resonance to vary inversely as the neutron velocity. Knowledge of the position and width of the first resonance would determine the neutron energy for which the inverse-velocity variation of absorption cross section ceases.

From examination of published data for some 52 stable isotopes, it is shown that it is possible to obtain an estimate of the neutron

energy at which the first resonance occurs from the thermal neutron absorption cross section. The empirical relation obtained from the experimental information is in qualitative agreement with the indications of a simplified version of the resonance theory of the nucleus of Breit-Wigner.

SOURCES OF ISOTOPIC DATA

The physical data for 34 isotopes, for which the thermal absorption cross section σ_{ath} and the neutron energy for the first resonance E_R have been assigned with reasonable assurance, are presented in table I.

Neutron cross-section data were taken principally from reference 2 in which the graphs of total cross section as a function of neutron energy served to locate generally the first few well-defined resonances. The specific energies at which the resonances occurred and isotopic assignment were verified for most of the isotopes from the original papers referred to in reference 2. A few elements listed, composed of a number of isotopes, contain a single preponderant isotope; the first strong resonance indicated on the total cross-section curve was assigned to this isotope.

For elements for which fairly complete data are available, there is usually a small gap in the total cross-section curve in the neutron energy range between the upper limit available from slow neutron spectrometers and the lower limit of particle accelerator neutron sources. Where values of total cross sections at these limits matched, it was assumed that no resonances occurred in this gap.

Isotopic thermal absorption cross sections and relative isotopic abundances of the elements were taken from references 3 to 7; the pile oscillator values of thermal absorption cross section were chosen wherever available. A few unknown isotopic thermal absorption cross sections were estimated from the known thermal absorption cross sections for the other isotopes of the element and the relative isotopic abundances. Additional resonance data were obtained from references 8 to 13.

Data on nine elements, each consisting principally of two isotopes with known thermal-absorption cross sections and having well-defined resonance peaks on the total cross-section curves are presented in table II. The lowest two resonance peaks have been assigned to the two individual isotopes in accordance with an empirical relation to be observed from the data of table I.

CORRELATION OF THERMAL ABSORPTION CROSS SECTION WITH NEUTRON ENERGY FOR FIRST RESONANCE

The dependence of thermal-absorption cross-section σ_{ath} (corresponding to an energy of 0.025 ev) on the neutron energy for the first resonance E_R for the isotopes of table I is presented in figure 1. The even-even, even-odd, odd-even, and odd-odd nuclei are indicated as such. With the exception of the two odd-odd lithium and nitrogen nuclei, there is a general correlation between σ_{ath} and E_R . It is apparent that E_R increases with decreasing σ_{ath} rather irregularly. It is, however, impossible to draw any conclusions concerning differences in the behavior of even-even, even-odd, and odd-even nuclei.

The dependence of σ_{ath} on E_R for the nine pairs of isotopes of table II is presented in figure 2. The well-defined resonances for each element have been assigned to the isotopes of the element in accordance with the general relation represented in figure 1. All of these isotopes happen to be odd-even nuclei with exception of the odd-odd boron isotope. Again, although the scatter in the data is large, the same general relation holds.

Analysis in reference 13 of the B^{10} neutron cross-section data indicates the presence of resonances at energies below the well-defined resonance at 2 Mev; the reference suggests that a number of resonances combine to form a broad peak near 100,000 electron volts. For energies in the region of 100,000 electron volts, the odd-odd boron isotope still departs significantly from the other nuclei.

A reason for the large scatter at the high energy resonances may be the following: The low energy first resonances are observed principally in heavy nuclei for which neutron capture with gamma or beta emission is the dominant absorption reaction. The neutrons involved have minimum angular momentum, and resonance processes involving them would be expected to be related to the thermal cross section, which is also due to these s-neutrons. The high energy first resonances occur mainly in light nuclei involving neutron capture with emission of various particles; the neutrons involved may possess one or more units of angular momentum, so the resonance processes are not expected to be related to the thermal-absorption process. For example, as cited in reference 14, the resonance absorption of neutrons by Li^6 with alpha emission at energies of about 250,000 ev is known to be due to p-neutrons (neutrons with one orbital unit of angular momentum).

The data of figures 1 and 2 are replotted in figure 3 for comparison. The paired isotopic data fall within the scatter of the data of

figure 1. Except for the three odd-odd nuclei Li^6 , B^{10} , and N^{14} , all of the available isotopic data have some measure of correlation.

Additional contributory evidence of the validity of the general relation indicated in figure 3 is presented in table III. The resonance energies qualitatively indicated in the table fall within the scatter of data in figure 3.

IMPLICATIONS FROM NEUTRON RESONANCE THEORY

The general dependence of σ_{ath} on E_R shown in figure 3 may be explained by the theory of excited states of the compound nucleus. Development and application of this theory are presented in references 15 and 16; it will be shown that after introducing some fairly general experimental information into the theory, the theory approximates the experimental data concerning the individual nuclei.

The cross section for an absorption or scattering process as a function of the energy of the incident particle near an isolated resonance is given by the Breit-Wigner single level formula. Inasmuch as the data in question are concerned with energies below the first level, the single level formula will essentially give correct results down to very low energies.

The absorption cross section σ_a for a neutron of kinetic energy E incident upon a nucleus with a resonance level occurring at a neutron energy E_R (both energies measured in the center of mass system) is given by

$$\sigma_a = \pi \lambda \lambda_R g \left[\frac{\Gamma_a \Gamma_n}{\frac{\Gamma^2}{4} + (E - E_R)^2} \right] \quad (1)$$

where $2\pi\lambda$ and $2\pi\lambda_R$ are the neutron wave lengths corresponding to the energies E and E_R , respectively, and Γ_a and Γ_n are the energy widths for the emission of a γ -ray or a charged particle (neutron capture) and the emission of a neutron (scattering), respectively, at the energy E_R . The total width Γ is given by the sum of the partial widths Γ_a and Γ_n , which are measures of the relative probability of neutron absorption and scattering.

The quantity g is a statistical weight factor determining the fraction of the total resonance states of the compound nucleus corresponding to a particular process. If a neutron has no angular momentum with respect to the nucleus by which it is captured, which is usually

the case, and if this nucleus has the spin I , then the quantity g is given by

$$g = \frac{1}{2} \left(1 \pm \frac{1}{2I + 1} \right) \quad (2)$$

For large I , g has a value of about $\frac{1}{2}$; for I equal to zero, only the plus sign is significant and g has its maximum value of 1; it has its minimum value of $\frac{1}{4}$ for I of $\frac{1}{2}$. If, for simplicity, a value of g equal to $\frac{1}{2}$ is introduced in equation (1), the largest error resulting in σ_a is a factor of 2.

The remaining quantities affecting σ_a are the neutron absorption and scattering widths Γ_a and Γ_n . Empirical and theoretical rules for estimating these values for various nuclei are presented in references 15 and 16. The absorption width Γ_a corresponding to the emission of γ -rays or of charged particles has been inferred from experimental data. Bethe (reference 15) has summarized the results for widths corresponding to γ -ray emission; his results indicate that Γ_a are of the order of 0.1 to 1 electron volt for most of the medium heavy nuclei; for light nuclei (as obtained from proton capture data) Γ_a is of the order of 1 to 10 electron volts. An approximate expression for the neutron width may be obtained from experimental data summarized in references 15 and 17 and from the theoretical discussion in references 16 and 18. The results can be represented by the following equation:

$$\Gamma_n = C \sqrt{E_R} D \quad (3)$$

where C is constant for a given nucleus and varies from 10^{-4} to $10^{-3} \text{ (ev)}^{-\frac{1}{2}}$ for various nuclei and D is the resonance level spacing.

The resonance level spacing D is not known for most nuclei. If, however, D is taken as being approximately equal to the kinetic energy E_R of the neutrons corresponding to the first resonance, equation (3) becomes

$$\Gamma_n = C(E_R)^{3/2} \quad (4)$$

In order to check the values of Γ_a and Γ_n given and to determine C of equation (4) more precisely, use is made of the experimental data of reference 1 wherein measurements of resonance scattering and resonance absorption integrals and average values of the resonance scattering fraction Γ_n/Γ are presented for a number of elements and isotopes.

From these data, values of $g\Gamma$ have been computed; by assuming a value of g of $\frac{1}{2}$ (for reasons explained previously) the width values Γ_n and Γ_a have been calculated for these elements and isotopes. These data are presented in table IV. The widths Γ_n and Γ_a are also represented as a function of E_R in figures 4 and 5, respectively. The dependence of Γ_n on E_R is reasonably well represented by equation (4) with $C = 5 \times 10^{-4} \text{ (ev)}^{-\frac{1}{2}}$, which is represented by the straight line in figure 4. The absorption widths Γ_a increase with E_R as indicated in figure 5; the average is about 0.1 electron volt as claimed by Bethe.

If the absorption cross section is measured in barns and neutron energies and widths are measured in electron volts, the single resonance level formula of equation (1) may be written

$$\sigma_a = \frac{65.8 \times 10^4 g}{\sqrt{E} \sqrt{E_R}} \left[\frac{\Gamma_a \Gamma_n}{\frac{\Gamma^2}{4} + (E - E_R)^2} \right] \quad (5)$$

Using a value of g of $\frac{1}{2}$ and width Γ_n as given by equation (4) with a value of C of 5×10^{-4} , the absorption cross section σ_a is given by

$$\sigma_a = \frac{165 \Gamma_a E_R}{\sqrt{E} \left[\frac{(5 \times 10^{-4} E_R^{3/2} + \Gamma_a)^2}{4} + (E - E_R)^2 \right]} \quad (6)$$

For resonance energies above 1 electron volt, the effect of the total width in equation (5) or (6) is negligible so that the thermal absorption cross section σ_{ath} evaluated at E equal to 0.025 electron volt may be given by

$$\sigma_{ath} = \frac{1040 \Gamma_a}{E_R} \quad (7)$$

Inasmuch as Γ_a is almost independent of E_R , equation (7) provides the reason for the correlation between σ_{ath} and E_R .

Equation (7), with the assumption of Γ_a of 0.1 electron volt, is plotted in figure 3 and appears to agree fairly well with the experimental resonance data of the medium and heavy nuclei where the assumptions made are most valid. Equation (7) with a Γ_a of 10 electron volts, as appropriate for the case of light nuclei (in accordance with summary of experimental data in reference 15), is also plotted on figure 3 and is in fairly good agreement with the experimental results obtained for light nuclei.

The isotopes Gd^{157} , Sm^{149} , and Cd^{113} have resonance energies which are small compared with their widths so that equation (1) does not apply. The thermal-absorption cross section at 0.025 electron volt for Sm^{149} is an average over the thermal spectrum of neutrons and so includes considerable contribution from the resonance peak. It is not surprising, therefore, that these isotopes (fig. 3) show cross sections in excess of that given by equation (7).

CONCLUDING REMARKS

Examination of published data for some 34 isotopes indicates that the neutron energy for which the first resonance is observed is related to the magnitude of the thermal absorption cross section in a way indicated by the theory of the compound nucleus.

The empirical relation is applied to nine pairs of additional isotopes with well-defined resonances, but with uncertain isotopic assignment, as additional evidence of the correlation.

Lewis Flight Propulsion Laboratory,
National Advisory Committee for Aeronautics,
Cleveland, Ohio.

REFERENCES

1. Harris, S. P., Muehlhause, C. O., and Thomas, G. E.: Low Energy Neutron Resonance Scattering and Absorption. Phys. Rev., 2d ser., vol. 79, no. 1, July 1, 1950, pp. 11-18.
2. Adair, Robert K.: Neutron Cross Sections of the Elements. Review of Modern Phys., vol. 22, no. 3, July 1950, pp. 249-289.
3. Nuclear Data Group: Nuclear Data. NBS Circular 499, U. S. Commerce Dept., Bur. Standards, Sept. 1, 1950.

4. Pomerance, H.: Capture Cross Section of the Elements as Determined with Pile Oscillator. Quarterly Prog. Rep. ending Dec. 15, 1949, ORNL-577, Ser. A, Oak Ridge Nat. Lab., Dec. 15, 1949, pp. 25-35. (Contract No. W-7405, eng 26.)
5. Way, K., and Haines, G.: Thermal Neutron Cross Sections for Elements and Isotopes. Rep. CNL-33, Ser. B, Oak Ridge Nat. Lab., Feb. 29, 1948. (Contract No. W-35-058, eng 71.)
6. Pomerance, H., and Hoover, J. I.: Thermal Neutron Absorption Cross Sections of Separated Isotopes. Phys. Rev., 2d ser., vol. 73, no. 10, May 15, 1948, p. 1265.
7. Pomerance, H., and Arnette, T.: Stable-Isotopes Cross Sections. Quarterly Prog. Rep. ending Dec. 20, 1950, ORNL-940, Ser. A, Oak Ridge Nat. Lab., March 15, 1951, pp. 43-44 (Contract No. W-7405, eng 26.)
8. Dunning, J. R.: Columbia Univ. Prog. Rep. for Oct., Nov., and Dec., 1949. Rep CUD-47, Tech. Information Div., ORE, AEC (Oak Ridge, Tenn.), March 1, 1950, p. 3. (Contract No. AT-30-1-Gen-72.)
9. Dunning, J. R.: Columbia Univ. Prog. Rep. for July, Aug., and Sept., 1949. Rept. CUD-45, Tech. Information Div., ORE, AEC (Oak Ridge, Tenn.), Dec. 1, 1949. (Contract No. AT-30-1-Gen-72.)
10. Melkonian, Edward: Slow Neutron Velocity Spectrometer Studies of O_2 , N_2 , A, H_2 , H_2O , and Seven Hydrocarbons. Phys. Rev., 2d ser., vol. 76, no. 12, Dec. 15, 1949, pp. 1750-1759.
11. Bockelman, C. K., Peterson, R. E., Adair, R. K., and Barshall, H. H.: Total Cross Section Measurements for Fast Neutrons. Phys. Rev., 2d ser., vol. 76, no. 2, July 15, 1949, pp. 277-279.
12. Wu, C. S., Rainwater, L. J., and Havens, W. W., Jr.: Slow Neutron Velocity Spectrometer Studies. III. I, Os, Co, Tl, Cb, Ge. Phys. Rev., 2d ser., vol. 71, no. 3, Feb. 1, 1947, pp. 174-181.
13. Inglis, D. R.: The $B^{10}(n,\alpha)$ Reaction and the Low Excited State of Li^7 . Phys. Rev., 2d ser., vol. 81, no. 6, March 15, 1951, pp. 914-919.
14. Peshkin, M., and Siegert, A. J. F.: On the $Li^6(n,\alpha)$ Reaction. Bull. Am. Phys. Soc., vol. 26, no. 3, abs. D5, April 26, 1951, p. 11.

4232-

15. Bethe, H. A.: Nuclear Physics. B. Nuclear Dynamics, Theoretical Rev. of Modern Phys., vol. 9, no. 2, April 1937.
16. Feshbach, H., Peaslee, D. C., and Weisskopf, V. F.: On the Scattering and Absorption of Particles by Atomic Nuclei. Phys. Rev., 2d ser., vol. 71, no. 3, Feb. 1, 1947, pp. 145-158.
17. Wigner, E. P.: Nuclear Reactions and Level Widths. Am. Jour. Phys., vol. 17, no. 3, March 1949, pp. 99-109.
18. Weisskopf, Victor F.: Compound nucleus and nuclear resonances. Helv. Phys. Acta, vol. 23, March 1950, pp. 187-200.

TABLE I - ISOTOPIC DATA



Isotope	Abundance in element (percent)	σ_{ath} (barns)	Reference	E_R (ev)	Reference
$^2\text{He}^4$	100	0.006	4	1,100,000	2
$^3\text{Li}^6$	7.30	890	(a)	270,000	2
$^4\text{Be}^9$	100	.0085	4	625,000	2
$^6\text{C}^{12}$	98.89	.0035	(a)	3,600,000	2
$^7\text{N}^{14}$	99.64	1.86	(a)	500,000	2
$^8\text{O}^{16}$	99.76	.001	(a)	440,000	2,3
$^9\text{F}^{19}$	100	.01	3	35,000	2
$^{11}\text{Na}^{23}$	100	.47	4	3,000	2
$^{12}\text{Mg}^{24}$	78.98	.027	7	230,000	2
$^{13}\text{Al}^{27}$	100	.22	4	2,300	3
$^{14}\text{Si}^{28}$	92.19	.08	7	600,000	2
$^{16}\text{S}^{32}$	95.06	.48	(a)	111,000	2
$^{20}\text{Ca}^{40}$	96.92	.0002	5	255,000	2
$^{23}\text{V}^{51}$	100	4.72	4	2,700	1
$^{25}\text{Mn}^{55}$	100	12.8	4	345	2
$^{27}\text{Co}^{59}$	100	34.2	4	120	2
$^{30}\text{Zn}^{67}$	4.12	1	(a)	480	1,2
$^{32}\text{Ge}^{73}$	7.9	13.7	4	95	1
$^{45}\text{Rh}^{103}$	100	150	4	1.30	2,3
$^{46}\text{Pd}^{108}$	26.7	11	5	24	3
$^{47}\text{Ag}^{107}$	51.35	30.0	6	16	2,3
$^{47}\text{Ag}^{109}$	48.65	83.7	6	5.1	2,3
$^{48}\text{Cd}^{113}$	12.34	24,000	5	0.17	2,3
$^{48}\text{Cd}^{116}$	7.66	1.40	5	110	3
$^{53}\text{I}^{127}$	100	6.06	4	20.3	2,3
$^{62}\text{Sm}^{149}$	13.84	65,000	3	0.096	2,3
$^{62}\text{Sm}^{152}$	26.63	135	3	10.0	2,3
$^{63}\text{Eu}^{153}$	52.23	240	3	0.465	3
$^{64}\text{Gd}^{157}$	15.71	240,000	3	0.031	2,3
$^{73}\text{Ta}^{181}$	100	21.3	4	4.1	2,3
$^{74}\text{W}^{186}$	28.64	34	5	18	2,3
$^{77}\text{Ir}^{191}$	38.5	1000	5	0.620	2,3
$^{77}\text{Ir}^{193}$	61.5	130	5	1.29	2,3
$^{79}\text{Au}^{197}$	100	95	4	4.8	2,3

^a Estimated from values of σ_{ath} known for other isotopes in element and relative isotopic abundances.

TABLE II - PAIRED ISOTOPES



Isotope	Abundance in element (percent)	σ_{ath} (barns)	Reference	E_R (eV)	Reference
${}^5\text{B}^{10}$	18.83	3800	(a)	2,000,000	2
${}^5\text{B}^{11}$	81.17	0.05	5	430,000	2
${}^{19}\text{K}^{39}$	93.08	2.13	(a)	70,000	2
${}^{19}\text{K}^{41}$	6.91	1.0	5	305,000	2
${}^{29}\text{Cu}^{63}$	69.09	4.3	3	570	3
${}^{29}\text{Cu}^{65}$	30.91	2.1	3	3000	3
${}^{31}\text{Ga}^{69}$	60.2	1.5	3	278	8
${}^{31}\text{Ga}^{71}$	39.8	3.4	3	100	8
${}^{35}\text{Br}^{79}$	50.57	10.9	5	34	9
${}^{35}\text{Br}^{81}$	49.43	2.25	5	125	9
${}^{49}\text{In}^{113}$	4.16	58	5	3.8	2,3
${}^{49}\text{In}^{115}$	95.84	197	5	1.44	2,3
${}^{51}\text{Sb}^{121}$	57.25	6.8	5	5.8	2,3
${}^{51}\text{Sb}^{123}$	42.75	2.5	5	15	2,3
${}^{75}\text{Re}^{185}$	37.07	101	5	2.15	2,10
${}^{75}\text{Re}^{187}$	62.93	75	5	4.5	2,10
${}^{81}\text{Tl}^{203}$	29.52	7.6	5	230	(b)
${}^{81}\text{Tl}^{205}$	70.48	0.11	5	4300	(b)

^a Estimated from values of σ_{ath} known for other isotopes in element and relative isotopic abundances.

^b Data obtained at Columbia University.

TABLE III - CONTRIBUTORY EVIDENCE



Isotope	Abundance in element (percent)	σ_{ath} (barns)	Reference	Resonance energy	Reference
$^{40}_{18}\text{A}$	99.60	0.60	3	Resonance above 10,000 ev suggested	12
$^{45}_{21}\text{Sc}$	100	11.8	4	Resonance cited at 1000-10,000 ev	1
$^{75}_{33}\text{As}$	100	4.14	4	Resonance cited at 100-1000 ev	1
$^{90}_{40}\text{Zr}$	51.46	.11	3	Resonance dip at 800,000 ev may be due to most abundant isotope	13
$^{93}_{41}\text{Nb}$	100	1.06	4	No resonance apparent below 1000 ev	14
$^{139}_{57}\text{La}$	100	8.8	4	No resonance apparent below 700 ev	2
$^{209}_{83}\text{Bi}$	100	.015	3	No resonance apparent below 1.4 Mev	2

TABLE IV - NEUTRON RESONANCE SCATTERING AND ABSORPTION
 WIDTHS AS CALCULATED FROM EXPERIMENTAL
 DATA OF REFERENCE 1



Isotope or element	σ_{ath} (barns)	E_R (ev)	$\frac{\Gamma_n}{\Gamma}$	$g\Gamma$ (ev)	Γ_n^a (ev)	Γ_a^a (ev)
$^{13}\text{Al}^{27}$	0.22	2300	0.99	11.8	23.3	0.24
$^{25}\text{Mn}^{55}$	12.8	345	.99	12.5	24.8	.25
$^{27}\text{Co}^{59}$	34.2	120	.94	1.58	2.96	.19
$^{29}\text{Cu}^{all}$	3.6	~1000	.95	9.40	17.9	.94
$^{31}\text{Ga}^{all}$	2.8	~ 200	.95	1.35	2.57	.13
$^{33}\text{As}^{75}$	4.1	~ 500	.72	.89	1.28	.50
$^{45}\text{Rh}^{103}$	150	1.30	.043	.0053	.0005	.01
$^{47}\text{Ag}^{107}$	30.0	15	.071	.067	.0095	.12
$^{47}\text{Ag}^{109}$	83.7	5.1	.038	.20	.015	.39
$^{51}\text{Sb}^{all}$	5.3	~ 5	.21	.0050	.0021	.008
$^{53}\text{I}^{127}$	6.06	20.3	.31	.055	.034	.076
$^{62}\text{Sm}^{152}$	135	10	.66	.17	.22	.11
$^{72}\text{Hf}^{all}$	102	~ 1	.17	.0023	.0008	.004
$^{73}\text{Ta}^{181}$	21.3	4.1	.12	.020	.0047	.034
$^{74}\text{W}^{186}$	34	18	.81	.16	.26	.061
$^{75}\text{Re}^{all}$	84	~ 3	.11	.012	.0026	.021
$^{79}\text{Au}^{197}$	95	4.8	.14	.060	.017	.10
$^{81}\text{Tl}^{203}$	7.6	230	.80	.80	1.27	.32

^a Calculated using statistical weight factor g of $\frac{1}{2}$.

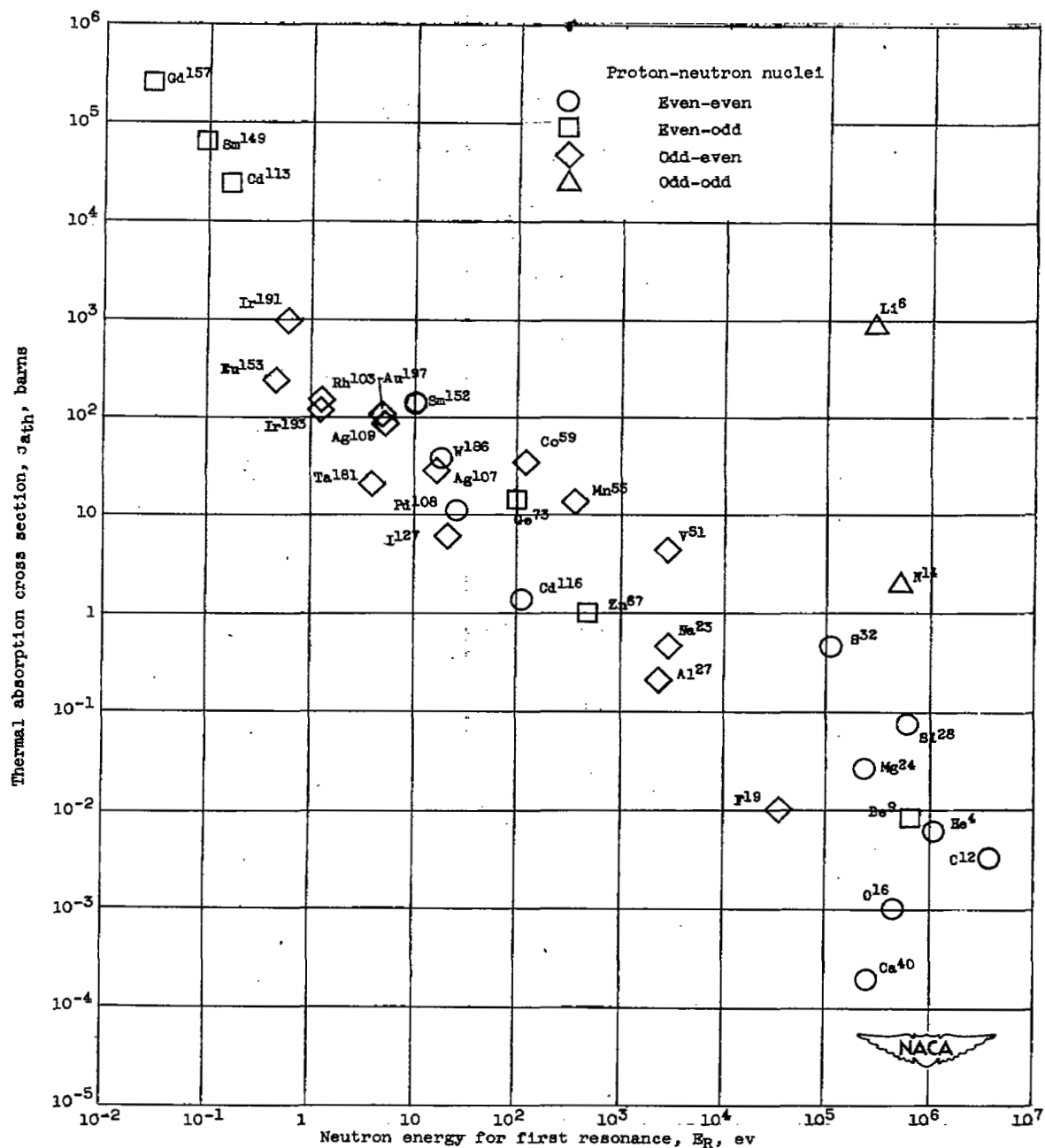


Figure 1. - Isotopic thermal neutron absorption cross section as related to neutron energy for first resonance.

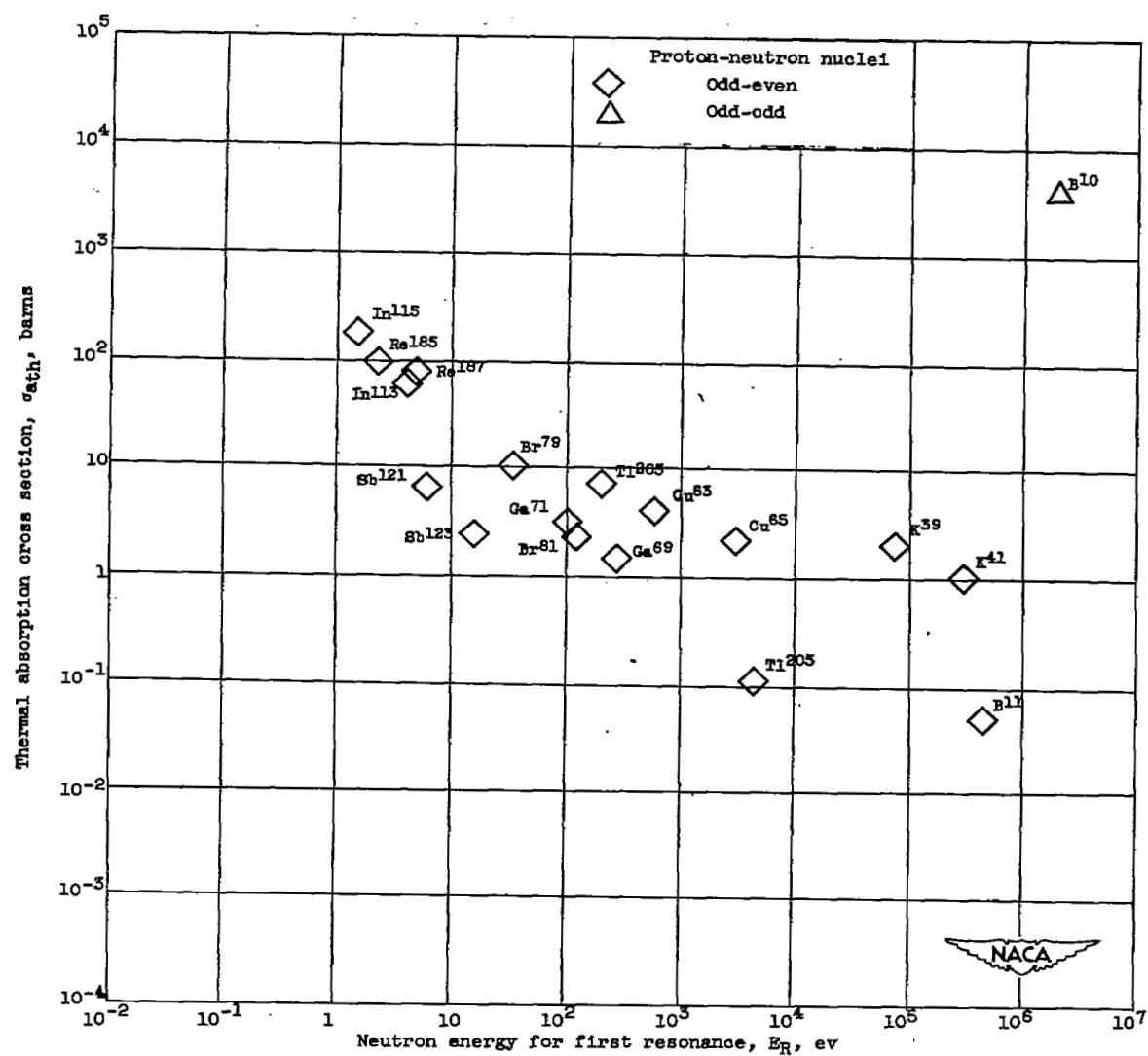


Figure 2. - Isotopic thermal neutron absorption cross section as related to neutron energy for first resonance for paired isotopes.

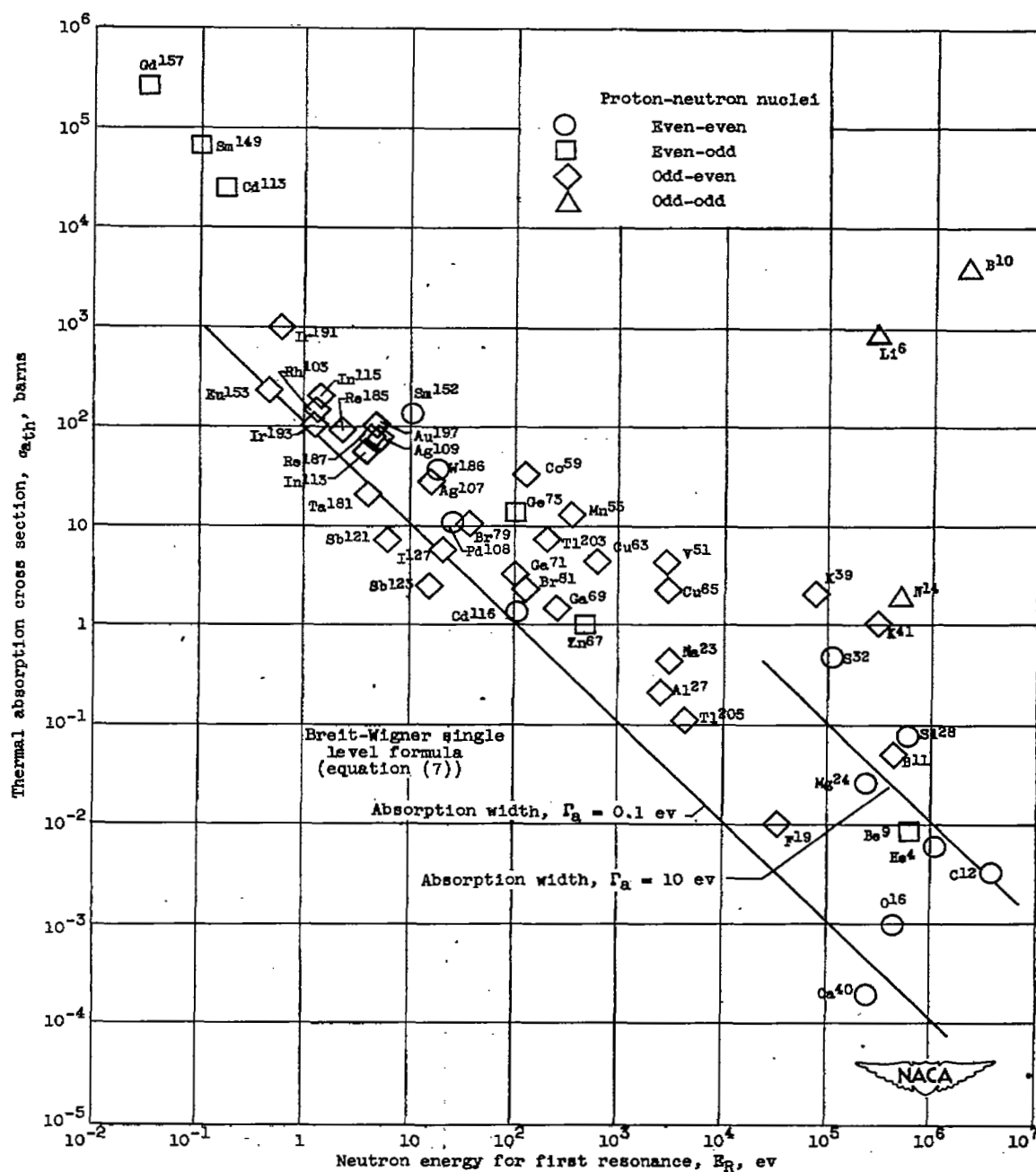


Figure 3. - Isotopic thermal neutron absorption cross section as related experimentally to neutron energy for first resonance and qualitative indications of Breit-Wigner single level formula.

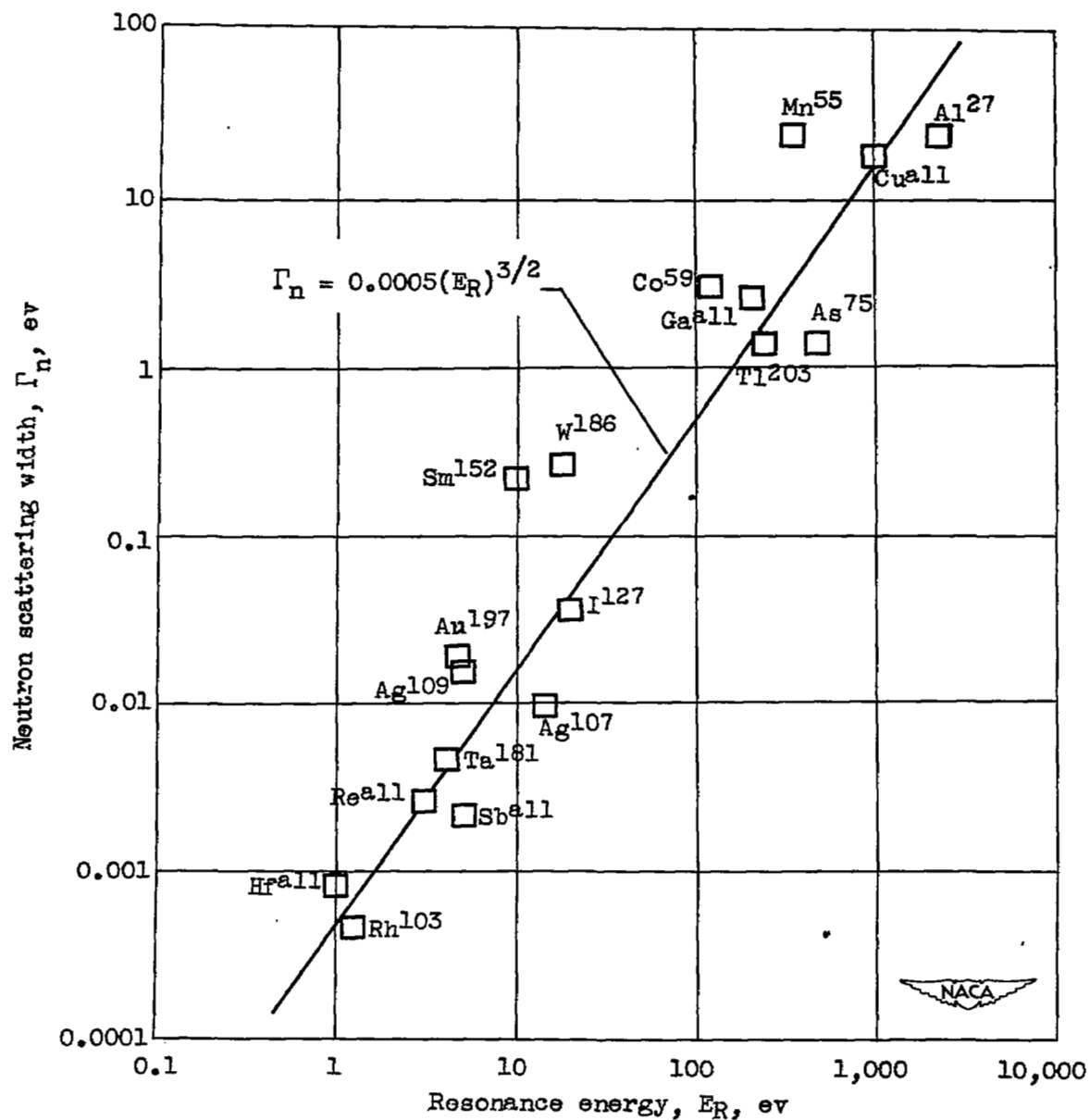


Figure 4. - Variation of neutron scattering width with resonance energy as calculated from data of reference 1. Statistical weight factor g assumed equal to $1/2$.

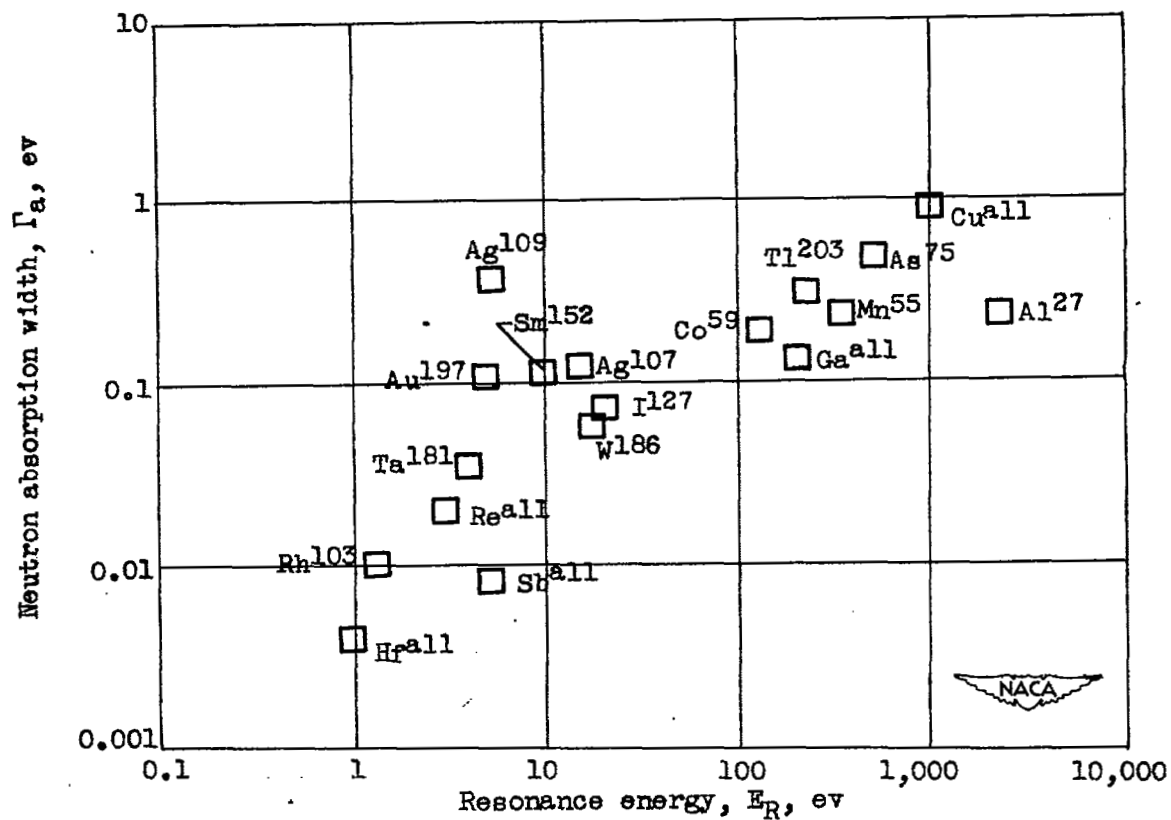


Figure 5. - Variation of neutron absorption width with resonance energy as calculated from data of reference 1. Statistical weight factor g assumed equal to $1/2$.

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